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VLBI2010 and the Westford Station – The Path Forward

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Abstract

For the past three years the role of the Westford antenna in geodetic VLBI has been two-fold. Over this time its primary purpose has been to participate in standard S/X-band geodetic VLBI observations. In its secondary role the Westford antenna has been converted into a research instrument, facilitating the development of the broadband geodetic VLBI observing technique. As a research instrument, the Westford antenna incorporates a commercially-available ETS-Lindgren 3164 quadridge antenna as a radio telescope feed. The system also uses the VLBI2010 data acquisition system that incorporates digital backends (DBEs) implementing a polyphase filter bank processor. The process of converting the station from its mode of operations to a research instrument often introduces subtle anomalies that must be diagnosed prior to broadband observing. Furthermore, this bifurcation of the station's role is not in line with the goals of the VLBI2010 specifications. Until recently it has not been possible for the Westford station to serve as both an operational and research instrument without conversion for two reasons: poor sensitivity and incompatibility of backend baseband filter bandwidths.

The poor sensitivity of the Westford antenna as a broadband radio telescope is in large part due to the commercial broadband feed which was readily available when the proof-of-concept VLBI2010 observations were initiated. However, with the materialization of the quadridge flared horn (QRFH) by the California Institute of Technology and with the improvements in the DiFX software correlator, the necessary components are now available to upgrade the Westford station to full-broadband capability while adhering to the mandate to maintain backwards compatibility with the legacy S/X systems. In this paper we will present the path forward for upgrading the Westford site to full-broadband capability while maintaining S/X compatibility.

1. Dual Role of the Westford Station within the IVS

For the past three years the Westford station has served dual roles within the IVS network. Its primary responsibility, which it has served for the past 20 years, is to participate in scheduled IVS observing sessions. In 2012 the Westford station participated in 62 IVS sessions in which it was configured with its operational S/X band receiver that is sensitive to circular polarization. In its second role the Westford station serves as a broadband VLBI instrument to facilitate development and testing of receiver hardware for the next-generation VLBI network. This mode of operation, however, is not sustainable in the long-term future of the Westford station.

The main drawback to this operational arrangement is that the antenna must be manually reconfigured for either S/X band or broadband observing; simultaneous S/X/broadband observing is not currently possible for reasons that are discussed in Section 3. Converting the Westford station from S/X to broadband requires removal of the S/X receiver from its prime focus installation. The broadband frontend is subsequently hoisted into place, the necessary cable and cryogenic connections are made, and the receiver is finally cooled. The conversion process requires at least two days to transition from one receiver to the other, and frequently this transition is not seamless.

Furthermore, this mode of operation is not in-line with the specifications set forth by VLBI2010, that being 24 hour uninterrupted observing.

2. Proof-of-Concept System and Characteristics

A block diagram and photos of the proof-of-concept broadband receiver frontend are shown in Figure 1. The phased/noise couplers provide a means to inject calibration signals needed to correct instrumental delay and amplitude variations in post-processing, while a high-pass filter is incorporated to inhibit saturation of the frontend LNA by either in-band or out-of-band RFI.

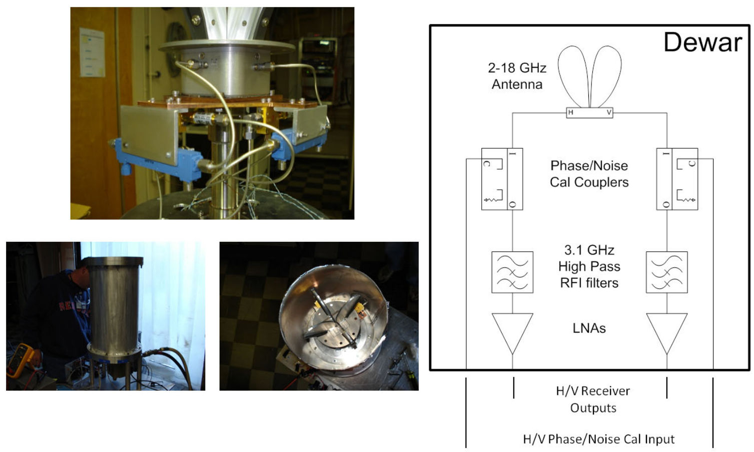

Figure 1. Photos of the proof-of-concept receiver frontend and associated block diagram.

When the broadband observing technique was first conceived, a broadband feed matched to the Westford antenna optics was not available. For this reason, the commercially-available ETS-Lindgren 3164 quadridge antenna was incorporated as the Westford radio telescope feed. However, the 3164 quadridge antenna possesses characteristics that make it a poor radio telescope feed, and so the sensitivity of the Westford antenna was poor. Figure 2 shows the measured aperture efficiency and system temperature of the Westford station when outfitted with the proof-of-concept receiver.

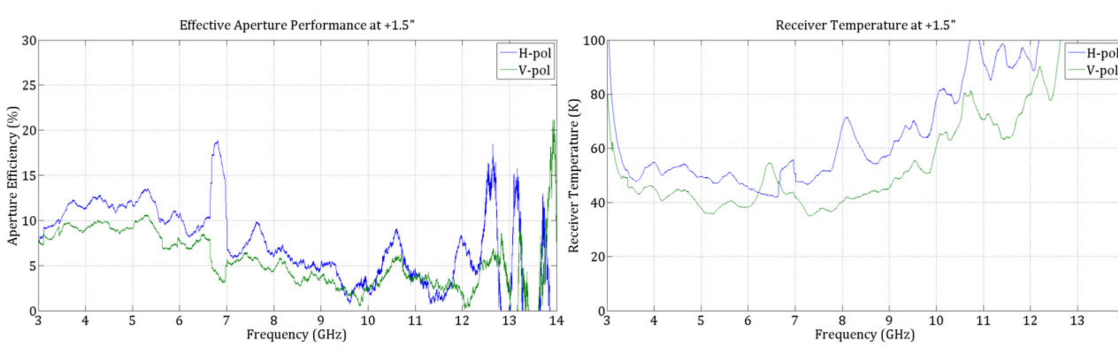

Figure 2. Measured aperture efficiency and system noise temperature of the proof-of-concept system at this optimum focus setting.

Despite the poor sensitivity, useful broadband observations were made enabling the demonstration of the broadband delay extraction technique. Broadband observations of four 512 MHz frequency bands spanning 6.4 GHz to 8.4 GHz were made with the proof-of-concept receiver and subsequently fringe fit with a broadband delay fringe fitting algorithm. Figure 3 shows the raw and phase calibrated fringe fit results obtained from broadband observations made with the Westford proof-of-concept receiver. We see from this result that the raw fringe fit result is fraught with systematic delay variations from one observing band to the next and that the application of the phase cal correction properly aligns the phase of all the observing bands from which the broadband delay is determined by a linear phase versus frequency fitting process.

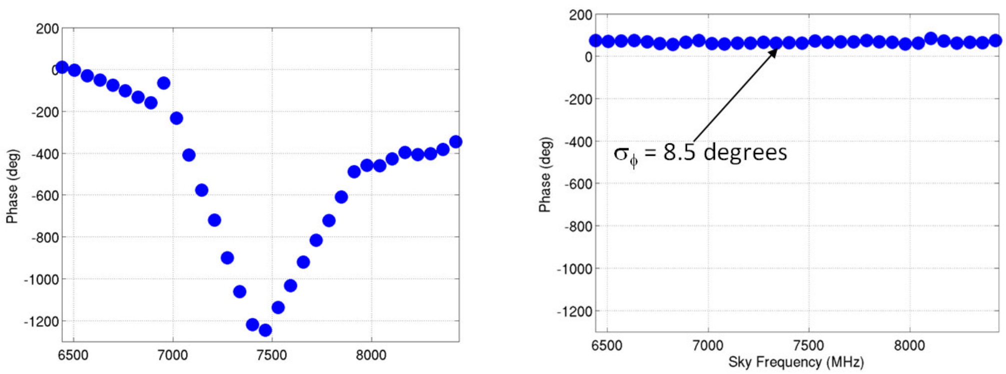

Figure 3. First 2 GHz (a) raw and (b) phase calibrated fringe phase results obtained with the proof-of-concept system.

Microwave signals generated by the receiver frontend are conveyed to the backend where they are downconverted into 512 MHz IF signals. The backend of the proof-of-concept receiver is a first-generation digital processor (DBE1) which incorporates a polyphase filter bank to subdivide the downconverted microwave signals into 32 MHz channels. This processor generates sixteen 32 MHz frequency channels uniformly distributed throughout the 512 MHz IF spectrum. However, the bandwidth limitation of the data recorders only permits eight of the sixteen channels to be recorded to disk so the eight channels shown in Figure 4 were selected. Since the net local oscillator frequency of each of these channels is fixed relative to the digitizer's sample rate (which itself is invariant) the distribution of the frequency channels in the IF spectrum is not adjustable. This is in contrast to the channelized spectrum produced by the video baseband converters, for which the IF distribution may be configured arbitrarily.

3. Upgrade Issues

Both the lack of sensitivity and its sensitivity to RFI disqualify the proof-of-concept receiver frontend as a candidate VLBI2010 frontend for the Westford antenna. The aperture efficiency and noise temperature shown in Figure 2 correspond to an SEFD of approximately 20000 Jy, while the VLBI2010 specification is 2500 Jy. The inclusion of the 3.1 GHz high-pass filter necessary to prevent S-band from saturating the frontend inhibits S-band observations, which is incongruent with the VLBI2010 specifications. Next-generation geodetic VLBI receivers must support S-band observations so that they may co-observe with stations which possess legacy S/X band hardware.

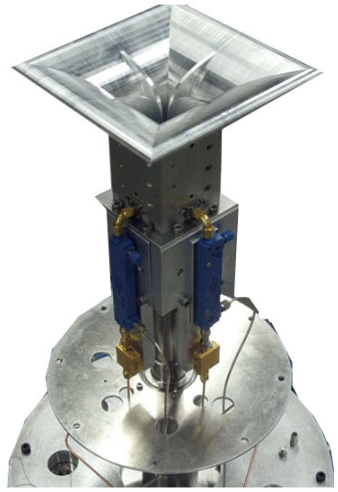

Figure 4. Photo of the new Westford broadband receiver frontend.

Co-observation of legacy and next-generation receivers also raises an issue of polarization compatibility. All legacy S/X band receivers in the IVS network are sensitive to circularly polarized radio signals, while all wideband radio telescope feeds under consideration for VLBI2010 are sensitive to linearly-polarized signals. There are two possible solutions to this compatibility issue.

The first solution is to convert the linearly polarized signals in the receiver frontend to circular polarization. This can be accomplished through the use of commercially available microwave 90° hybrids and power combiners. In incorporating such a solution, the phase and amplitude balance of such components is critical in order to maintain the integrity of the linear-to-circular transformation. Fortunately, the broadband performance of such components is sufficient to maintain 20 dB of cross-polarization isolation in the circular basis which is adequate for the goals of VLBI2010 [1]. The second solution to the polarization conundrum is to perform a proper polarimetric combination in post-observation processing [2]. This method has been incorporated into *fourfit* and requires knowledge of the differential parallactic angle between any stations observing in a linear polarization basis.

Post-observation processing also provides a solution to the incompatibility of LO frequencies and channel bandwidths associated with the PFB and legacy video baseband converters. The correlation of incompatible frequency channels is now accommodated by the DiFX software correlator using the zoom-mode feature. Though there are some numerical considerations to be observed (i.e., FFT sizes), the only fundamental requirement of using this correlator mode is that the frequency channels possess spectral overlap.

4. Next-generation Westford Receiver Frontend

The VLBI receiver is mounted in the prime focus location on the Westford antenna. Relative to other radio telescopes, the Westford dish requires a feed possessing a wide beam (80° subtended angle). For this reason a quadridge flared horn (QRFH) feed design [3] was developed for the Westford dish by the California Institute of Technology. The QRFH design possesses a sharp low frequency cutoff which in effect serves to high-pass filter the spectrum that is presented to the

LNA; this cutoff frequency is a parameter of the feed design. As alluded to in Section 2 ("Proof-of-Concept System and Characteristics"), low frequency RFI is of great concern to next-generation VLBI receivers, so the high-pass feature of the QRFH is considered to be an attractive attribute of the design.

The QRFH that was designed for the Westford antenna was done so with a 2.2 GHz lower cutoff frequency to reject as much of S-band as possible while maintaining the ability to co-observe with legacy receivers. The new frontend will also incorporate microwave couplers to inject phase and noise calibration signals and uses the Caltech CRYO1-12 low noise amplifier as the first gain stage to achieve low noise operation. A photo of the Westford receiver frontend is shown in Figure 4.

Based on the simulated feed patterns of the Westford QRFH feed, the expected aperture efficiency of the Westford radio telescope was computed and is approximately 47% over the full bandwidth of the receiver. With this aperture efficiency the system noise temperature could be as high as 105K before the 2500 Jy VLBI2010 specification is violated. The actual system noise temperature is expected to be much lower.

Acknowledgements

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